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ABSTRACT

Crustal Evolution Education Project (CEEP) modules were designed to: (1) provide students with the methods and results of continuing investigations into the composition, history, and processes of the earth's crust and the application of this knowledge to man's activities and (2) to be used by teachers with little or no previous background in the modern theories of sea-floor spreading, continental drift, and plate tectonics. Each module consists of two booklets: a teacher's guide and student investigation. The teacher's guide contains all of the information present in the student investigation booklet as well as: (1) a general introduction; (2) prerequisite student background; (3) objectives; (4) list of required materials; (5) background information; (6) suggested approach; (7) procedure, including number of 45-minute class periods required; (8) summary questions (with answers); (9) extension activities; and (10) list of references. Focusing on how hot spots (dome-like bulges in earth's crust) may account for the three-arm type of rift valley system, models are made to illustrate doming, rifting, and breakup of a continental land mass. Major rivers occupying failed arms along the Atlantic Continental margins of Africa and South America are also named and located. (Author/JN)

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CRUSTAL EVOLUTION EDUCATION PROJECT

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How Do Continents Split Apart?

TEACHER'S GUIDE

Catalog No. 34W1010

For use with Student Investigation 34W1110
Class time: two 45-minute periods

Developed by
THE NATIONAL ASSOCIATION OF GEOLOGY TEACHERS

Produced and Distributed by
Ward's Natural Science Establishment, Inc. Rochester, NY • Monterey, CA

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NAGT Crustal Evolution Education Project

Edward C. Stoever, Jr., Project Director

Welcome to the exciting world of current research into the composition, history and processes of the earth's crust and the application of this knowledge to man's activities. The earth sciences are currently experiencing a dramatic revolution in our understanding of the way in which the earth works. CEEP modules are designed to bring into the classroom the methods and results of these continuing investigations. The Crustal Evolution Education Project began work in 1974 under the auspices of the National Association of Geology Teachers. CEEP materials have been developed by teams of science educators, classroom teachers, and scientists. Prior to publication, the materials were field tested by more than 200 teachers and over 12,000 students.

Current crustal evolution research is a breaking story that students are living through today. Teachers and students alike have a unique opportunity through CEEP modules to share in the unfolding of these educationally important and exciting advances. CEEP modules are designed to provide students with appealing firsthand investigative experiences with concepts which are at or close to the frontiers of scientific inquiry into plate tectonics. Furthermore, the CEEP modules are designed to be used by teachers with little or no previous background in the modern theories of sea-floor spreading, continental drift and plate tectonics.

We know that you will enjoy using CEEP modules in your classroom. Read on, and be prepared to experience a renewed enthusiasm for teaching as you learn more about the living earth in this and other CEEP modules.

About CEEP Modules...

Most CEEP modules consist of two booklets: a Teacher's Guide and a Student Investigation. The Teacher's Guide contains all the information and illustrations in the Student Investigation, plus sections printed in color, intended only for the teacher, as well as answers to the questions that are included in the Student Investigation. In some modules, there are illustrations that appear only in the Teacher's Guide, and these are designated by figure letters instead of the number sequence used in the Student Investigation.

For some modules, maps, rulers and other common classroom materials are needed, and in varying quantities according to the method of presentation. Read over the module before scheduling its use in class and refer to the list of MATERIALS in the module.

Each module is individual and self-contained in content, but some are divided into two or more parts for convenience. The recommended length of time for each module is indicated. Some modules require prerequisite knowledge of some aspects of basic earth science; this is noted in the Teacher's Guide.

The material was prepared with the support of National Science Foundation Grant Nos. SED 75-20151, SED 77-08539, and SED 78-25104. However, any opinions, findings, conclusions, or recommendations expressed herein are those of the author(s) and do not necessarily reflect the views of NSF.

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How Do Continents Split Apart?

INTRODUCTION

Molten lava carries heat from the earth's interior. The mid-ocean ridge system is a place where this lava reaches the floor of the ocean. At times, the lava even builds volcanic mountains that rise above the ocean's surface. However, the mid-ocean ridge system is not the only place having a high heat flow from the earth's interior. There are over 100 areas on our planet where very high heat flows are known to exist. These areas are called **hot spots.** Hot spots are dome-like bulges in the earth's crust having diameters of up to about 200 km. Some hot spots are at or near the crest of the mid-ocean ridge. The island of Iceland, on the crest of the mid-ocean ridge in the North Atlantic Ocean, is thought to lie over a hot spot. Tristan da Cunha, an island in the middle of the South Atlantic Ocean, may also lie over a hot spot. The island of Hawaii is also thought to lie over a hot spot. Hot spots are often associated with volcanic eruptions at some time in their history.

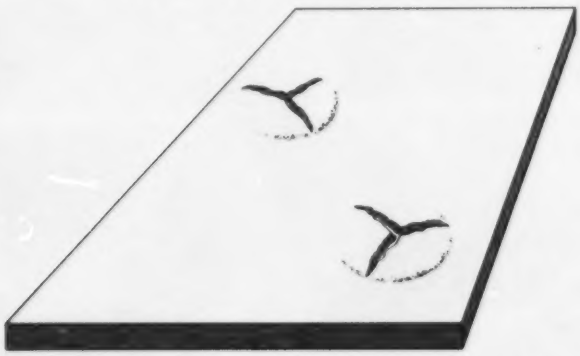


Figure 1. Three-armed rift valley system in hot spot domes.

Hot spots initially cause a **doming** of the land that may weaken the earth's lithosphere. Figure 1 shows domed areas of the lithosphere which have been broken by three-armed **rift valley** systems. Scientists have found similar rift valley systems on the continent of Africa. Rift valleys are long, relatively straight and steep-sided valleys. The valleys owe their origins to roughly parallel faults in the earth's crust.

If several hot spots join, then a line of weakness may form across an entire continent. When there are forces acting to split the continent, then it may be split along the rift valleys caused by hot spots.

How do the hot spots cause rift valleys? How do the rifts link up to allow splitting of a continent? What is the evidence for the relationship between hot spots and continental breakup?

PREREQUISITE STUDENT BACKGROUND

Students should know about the general characteristics of the lithosphere, the outline and topography of continents, sea-floor spreading and plate tectonic theory.

OBJECTIVES

After you have completed this activity, you should be able to:

1. Explain how hot spots may account for the three-armed type of rift valley system.
2. Sketch how rift valley systems may grow together during breakup of continents.
3. Name and locate major rivers that may occupy failed arms along the Atlantic continental margins of Africa and South America.

MATERIALS

10 x 10 cm pieces of scrap paper—three for each student.

Sheet of page-size blank paper—for each student.

Small pieces of masking or cellophane tape—four for each student.

Scissors—one pair for each student.

Metric ruler (optional)—one for each student.

Map, *The Physical World*, National Geographic Society, Educational Services, Department 79, Washington, D.C. 20036—one for each class.

Drawing compass (optional)—one for each student.

BACKGROUND INFORMATION

The relationship between hot spots, three-armed rift valley systems, and continental breakup is a new and controversial aspect of the plate tectonics theory. In addition to evidence provided by the geometry of continental margins, there are anomalous thick, linear sediment deposits on land that could have resulted from the filling of failed arms of ancient three-armed rift valley systems. Such sediment-filled, failed arms are called *aulacogens* (from the Greek meaning "born of furrows"). One of the best developed aulacogens in North America lies in southern Oklahoma parallel to the Texas-Oklahoma border. Its sediment filling is about 15 kilometers deep. Aulacogens are important not only because they offer evidence of the existence of three-armed rift valley systems but also because oil and gas deposits may be found in their thick sediment deposits. Therefore, finding aulacogens may aid the development of scientific theory and increase economic resources at the same time.

SUGGESTED APPROACH

This activity lends itself to a directed inquiry approach. Students can work alone or in pairs. It is advisable to stop the class at two or three critical places to check their understanding of the concepts. Critical questioning helps to clarify misconceptions and provide direction to the group.

PROCEDURE

Students make a model for the doming, rifting and breakup of a continental landmass and identify the parts of a rift valley system.

Key words: hot spots, rift valley, doming, failed arm

Time required: two 45-minute periods

Materials: paper, tape, scissors, ruler, drawing compass, atlas

1. Sketch, or use a drawing compass to make, three circles with a 3 to 5 cm radius on Worksheet 1. Position the circles as shown in Figure 2.

2. From the center of each circle, draw three lines at equal angles from each other (about 120°). Draw these lines like those shown in Figure 2.

The three circles represent hot spots. The three lines in each circle represent the three-armed rift valley system of each hot spot bulge.

3. Use scissors to cut along each straight line of the three-armed rift valley system in each imaginary circular hot spot.

Students make the necessary cuts to represent the fracture or rifting of the lithosphere. Check to make sure they do not cut any lines other than those of the rift valley systems.

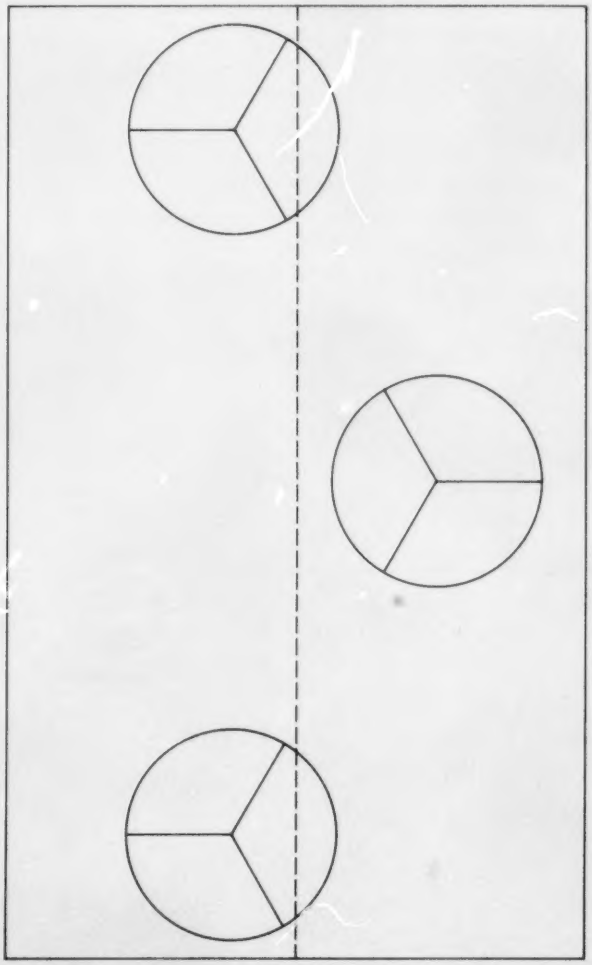


Figure 2. Pattern of hot spots and rift valley systems drawn on Worksheet 1.

4. Crumple the three pieces of scrap paper into small spherical shapes of about 3 cm in diameter. Next, place Worksheet 1 on your table with a crumpled piece of scrap paper under the center of each imaginary hot spot. Press the Worksheet down onto the crumpled papers.

5. In the space below, write a sentence that describes what hot spots do to the earth's crust (represented by Worksheet 1).

Hot spots cause a doming and cracking of the lithosphere which generally results in a three-armed rift valley system. Remind the students that the paper simulates the hot molten rock which causes the doming. Tell them to pay close attention to the shape of the rifts.

6. Remove the crumpled scrap paper from beneath Worksheet 1. Draw lines to show the connection between the arms of rift valleys that should link up if your imaginary earth's crust continued to split apart. Continue the line as if hot spots existed in alternating positions beyond the top and bottom of Worksheet 1. See Figure 3. Write "active arm" on each of the two arms of each hot spot that connects with rift valley arms of nearby hot spots.

Students extend the rifts until they link up. Some explanation may be required to explain why the rifts continue off their paper model.

7. Cut along the lines that show linkup of rift valleys. (Do not cut along the original dotted line up and down the center of Worksheet 1.) Separate the two halves of Worksheet 1 by about 2 cm. Tape the two halves to a sheet of blank paper. The opening represents an early stage of ocean formation between pieces of a continent that has broken apart.

8. Draw a line midway between the separated pieces of Worksheet 1. Label this line "mid-ocean ridge".

Each hot spot has a rift valley arm that failed to connect with a rift valley arm from another hot spot. Label each of these **"failed arm."** Because each of the failed arms represents a long valley in the earth's crust, a river might begin to flow along the failed arm and into the ocean.

Students now complete the cutting which results in complete breakup of their continent. They also label the parts of the rift valley systems and the mid-ocean ridge. See Answer Sheet 1.

Take the time to answer questions about why the ridge is in the center and how this can lead to a new ocean.

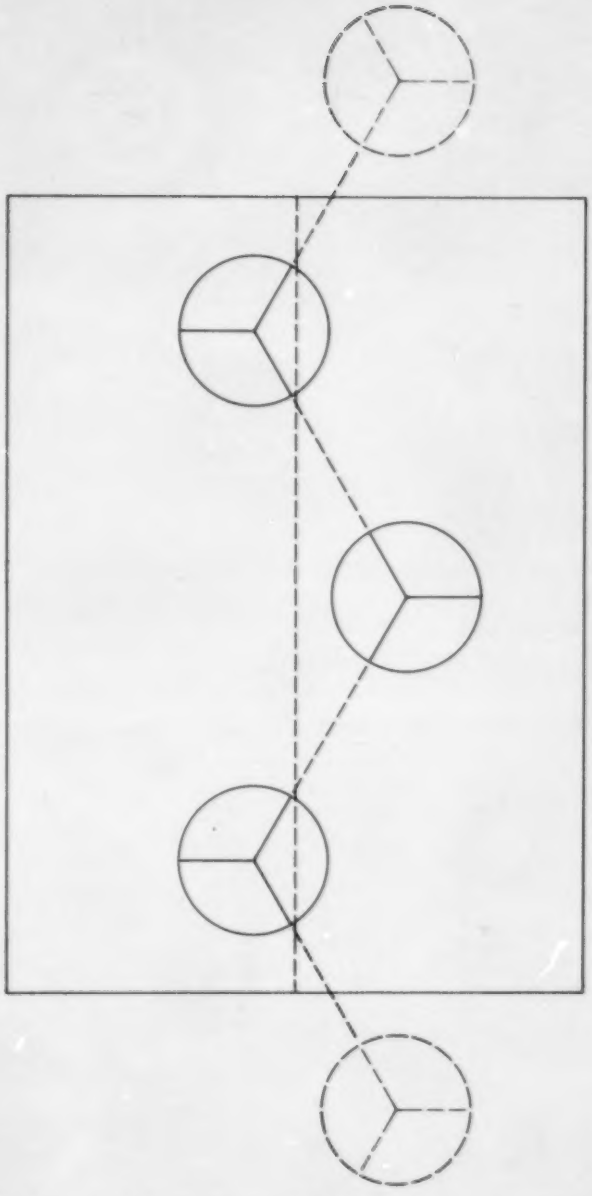


Figure 3. Linkup of rift valleys extending outward from hot spots. Worksheet 1.

9. Worksheet 2 shows a simplified outline of South America and Africa in a position just after they began to split apart 125 million years ago. Study a map of South America and Africa to find the major rivers that may occupy failed arms of ancient hot spots. Write the names of those rivers in their proper location on Worksheet 2.

10. Draw a hot spot and the three-armed rift valley system on each hot spot where you think it might have been in relation to each river, on Worksheet 2. Remember that these rivers represent the failed arms of the three-armed rift valley system.

Students examine South America and Africa on the map, *The Physical World* and label the rivers on Worksheet 2. Students then should construct three hot spots around these rivers. The hot spots should link up to give the necessary shape of South America and Africa.

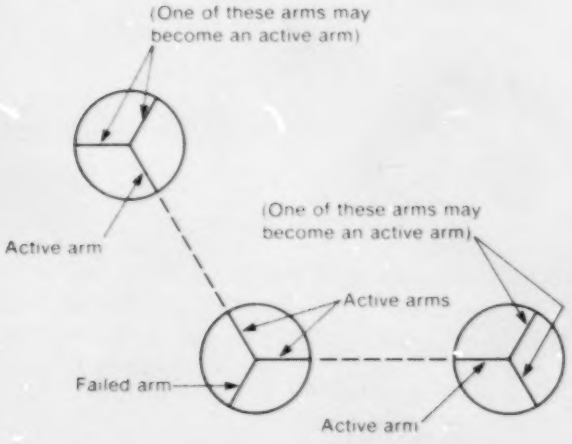
If a series of hot spots produced a line of weakness, the continent would split along that line. The result would be a new ocean with a ridge and a series of failed arms extending into each of the two new continents. Such arms would provide ready-made channels for drainage of the new continents and major rivers will flow through them; Amazon, Niger, Paraná. See Answer Sheet 2. Other rivers may seem to occupy failed arm positions, but confirming evidence is lacking.

SUMMARY QUESTIONS

1. What are hot spots? What are the first changes they cause in the earth's crust?

They are isolated areas of high heat flow and volcanism. They cause a doming and deep fissuring of the lithosphere.

2. Sketch a diagram to show how three hot spots might link up and label all active arms and failed arms.


(One of these arms may become an active arm)
Active arm
(One of these arms may become an active arm)
Active arms
Failed arm
Active arm

3. How might linkup of active arms allow formation of an ocean basin?

When a series of hot spots occur beneath a continent, they can cause a zone of weakened and fractured lithosphere. As new crustal material is created along this zone, the two broken continental fragments are slowly moved apart. This is the early stage of ocean formation.

4. What might happen to failed arms of hot spots?

Since they are troughs that extend from a domed continent into a new ocean, they are likely routes for the rivers that form the drainage system of the new continent.

EXTENSIONS

As your students become more familiar with the idea of continental breakup, a logical extension is to look at the world distribution of hot spots. This information can be gathered and compiled by your students on a large world map. There are at least 122 known hot spot locations of which 53 are in ocean basins and 69 are on continents. Africa provides the greatest number of examples of present day hot spots, with 35% of the world total. This represents far more than its size would indicate. Some of the rift valley systems of Africa are the Zambesi, Nakuru, and Afar. The suggested references provide detailed information on this topic.

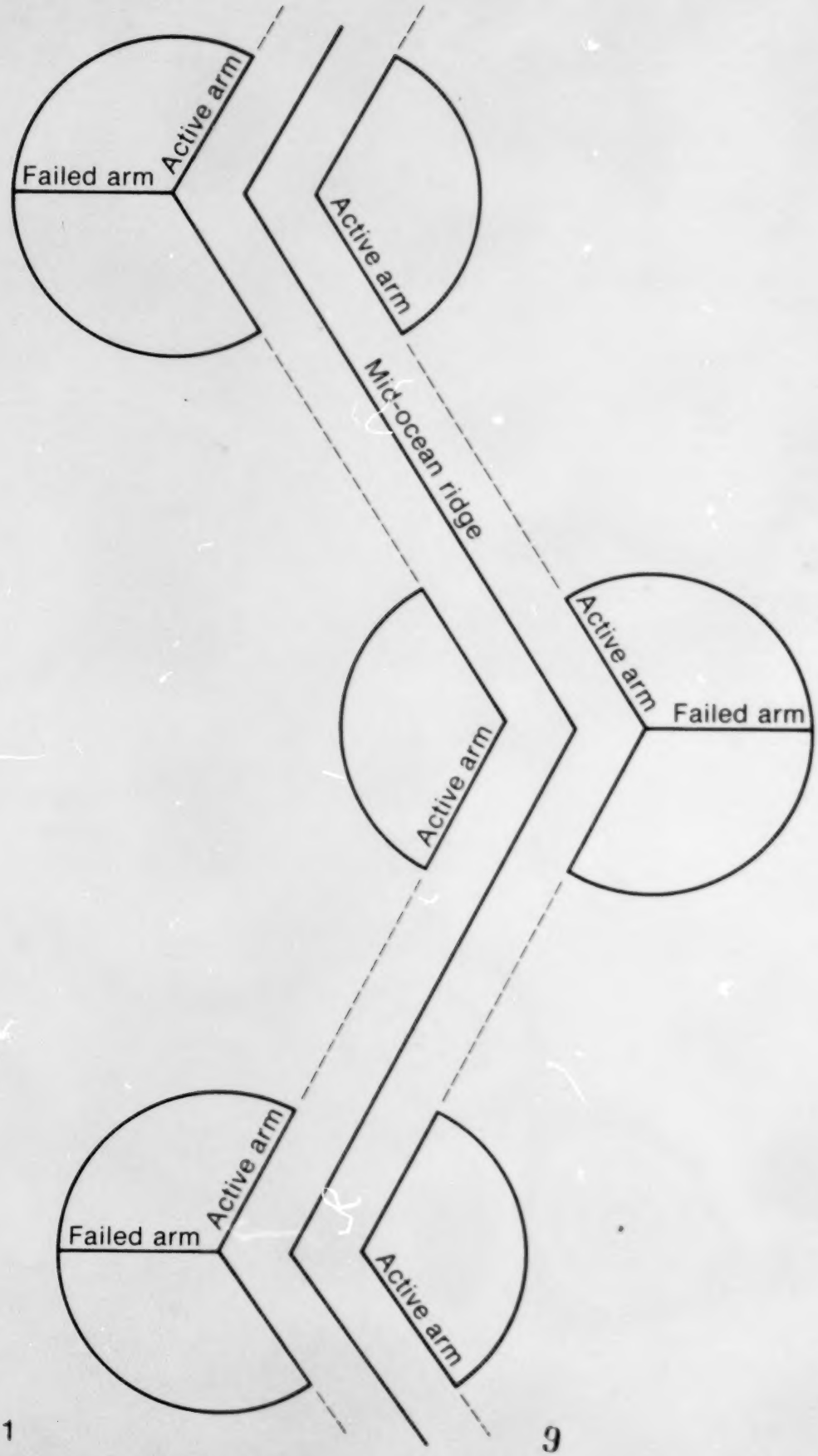
Study a map that shows the areas around the Red Sea and Gulf of Aden between northeast Africa and the Arabian Peninsula. Make a sketch map to show how this area might be explained by a hot spot near the junction of the Red Sea and Gulf of Aden.

This particular area will help students apply the general model to a specific locality.

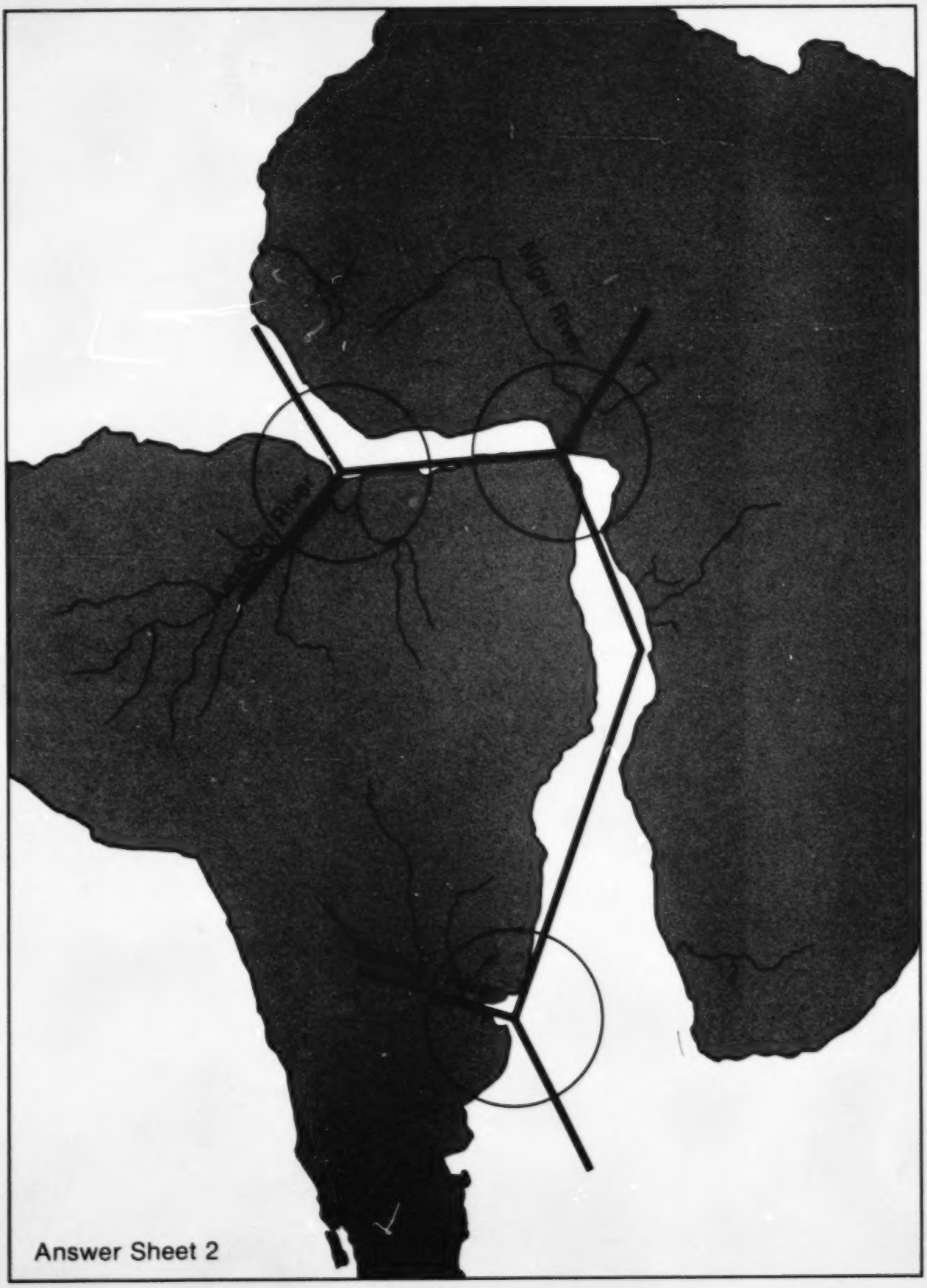
REFERENCES

Burke, K. C. and Wilson, J. Tuzo, 1976, Hot spots on the earth's surface. *Scientific American,* v. 235, no. 2 (August), p. 46–57.

Burke, K. C. and Dewey, J. F., 1973, Plume-generated triple junctions: key indicators in applying plate tectonics to old rocks. *The Journal of Geology,* v. 81, no. 4 (July), p. 406–433.



Answer Sheet 1



Answer Sheet 2

NAGT Crustal Evolution Education Project Modules

CEEP Modules are listed here in alphabetical order. Each Module is designed for use in the number of class periods indicated. For suggested sequences of CEEP Modules to cover specific topics and for correlation of CEEP Modules to standard earth science textbooks, consult Ward's descriptive literature on CEEP. The Catalog Numbers shown here refer to the CLASS PACK of each Module consisting of a Teacher's Guide and 30 copies of the Student Investigation. See Ward's descriptive literature for alternate order quantities.

CEEP Module	Class Periods	CLASS PACK Catalog No.
• A Sea-floor Mystery: Mapping Polarity Reversals	3	34 W 1201
• Continents And Ocean Basins: Floaters And Sinkers	3-5	34 W 1202
• Crustal Movement: A Major Force In Evolution	2-3	34 W 1203
• Deep Sea Trenches And Radioactive Waste	1	34 W 1204
• Drifting Continents And Magnetic Fields	3	34 W 1205
• Drifting Continents And Wandering Poles	4	34 W 1206
• Earthquakes And Plate Boundaries	2	34 W 1207
• Fossils As Clues To Ancient Continents	2-3	34 W 1208
• Hot Spots In The Earth's Crust	3	34 W 1209
• How Do Continents Split Apart?	2	34 W 1210
• How Do Scientists Decide Which Is The Better Theory?	2	34 W 1211
• How Does Heat Flow Vary In The Ocean Floor?	2	34 W 1212
• How Fast Is The Ocean Floor Moving?	2-3	34 W 1213
• Iceland: The Case Of The Splitting Personality	3	34 W 1214
• Imaginary Continents: A Geological Puzzle	2	34 W 1215
• Introduction To Lithospheric Plate Boundaries	1-2	34 W 1216
• Lithospheric Plates And Ocean Basin Topography	2	34 W 1217
• Locating Active Plate Boundaries By Earthquake Data	2-3	34 W 1218
• Measuring Continental Drift: The Laser Ranging Experiment	2	34 W 1219
• Microfossils, Sediments And Sea-floor Spreading	4	34 W 1220
• Movement Of The Pacific Ocean Floor	2	34 W 1221
• Plate Boundaries And Earthquake Predictions	2	34 W 1222
• Plotting The Shape Of The Ocean Floor	2-3	34 W 1223
• Quake Estate (board game)	3	34 W 1224
• Spreading Sea Floors And Fractured Ridges	2	34 W 1225
• The Rise And Fall Of The Bering Land Bridge	2	34 W 1227
• Tropics In Antarctica?	2	34 W 1228
• Volcanoes: Where And Why?	2	34 W 1229
• What Happens When Continents Collide?	2	34 W 1230
• When A Piece Of A Continent Breaks Off	2	34 W 1231
• Which Way Is North?	3	34 W 1232
• Why Does Sea Level Change?	2-3	34 W 1233

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WARD'S
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CEEP MODULE NO. NY2 1-3
ISBN: 0-88873-019-X
Printed in U.S.A.

CRUSTAL EVOLUTION EDUCATION PROJECT

NAME DATE

Student Investigation

Catalog No. 34W1110

How Do Continents Split Apart?

INTRODUCTION

Molten lava carries heat from the earth's interior. The mid-ocean ridge system is a place where this lava reaches the floor of the ocean. At times, the lava even builds volcanic mountains that rise above the ocean's surface. However, the mid-ocean ridge system is not the only place having a high heat flow from the earth's interior. There are over 100 areas on our planet where very high heat flows are known to exist. These areas are called **hot spots.** Hot spots are dome-like bulges in the earth's crust having diameters of up to about 200 km. Some hot spots are at or near the crest of the mid-ocean ridge. The island of Iceland, on the crest of the mid-ocean ridge in the North Atlantic Ocean, is thought to lie over a hot spot. Tristan da Cunha, an island in the middle of the South Atlantic Ocean, may also lie over a hot spot. The island of Hawaii is also thought to lie over a hot spot. Hot spots are often associated with volcanic eruptions at some time in their history.

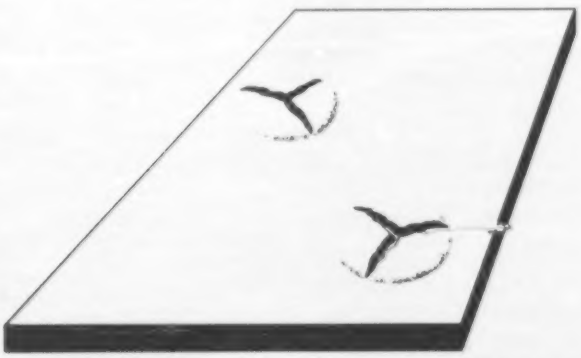

Figure 1. Three-armed rift valley system in hot spot domes.

Hot spots initially cause a **doming** of the land that may weaken the earth's lithosphere. Figure 1 shows domed areas of the lithosphere which have been broken by three-armed **rift valley** systems. Scientists have found similar rift valley systems on the continent of Africa. Rift valleys are long, relatively straight and steep-sided valleys. The valleys owe their origins to roughly parallel faults in the earth's crust.

If several hot spots join, then a line of weakness may form across an entire continent. When there are forces acting to split the continent, then it may be split along the rift valleys caused by hot spots.

How do the hot spots cause rift valleys? How do the rifts link up to allow splitting of a continent? What is the evidence for the relationship between hot spots and continental breakup?

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OBJECTIVES

After you have completed this activity, you should be able to:

1. Explain how hot spots may account for the three-armed type of rift valley system.
2. Sketch how rift valley systems may grow together during breakup of continents.
3. Name and locate major rivers that may occupy failed arms along the Atlantic continental margins of Africa and South America.

PROCEDURE

Materials: paper, tape, scissors, ruler, drawing compass, atlas

1. Sketch, or use a drawing compass to make, three circles with a 3 to 5 cm radius on Worksheet 1. Position the circles as shown in Figure 2.
2. From the center of each circle, draw three lines at equal angles from each other (about 120°). Draw these lines like those shown in Figure 2.

The three circles represent hot spots. The three lines in each circle represent the three-armed rift valley system of each hot spot bulge.

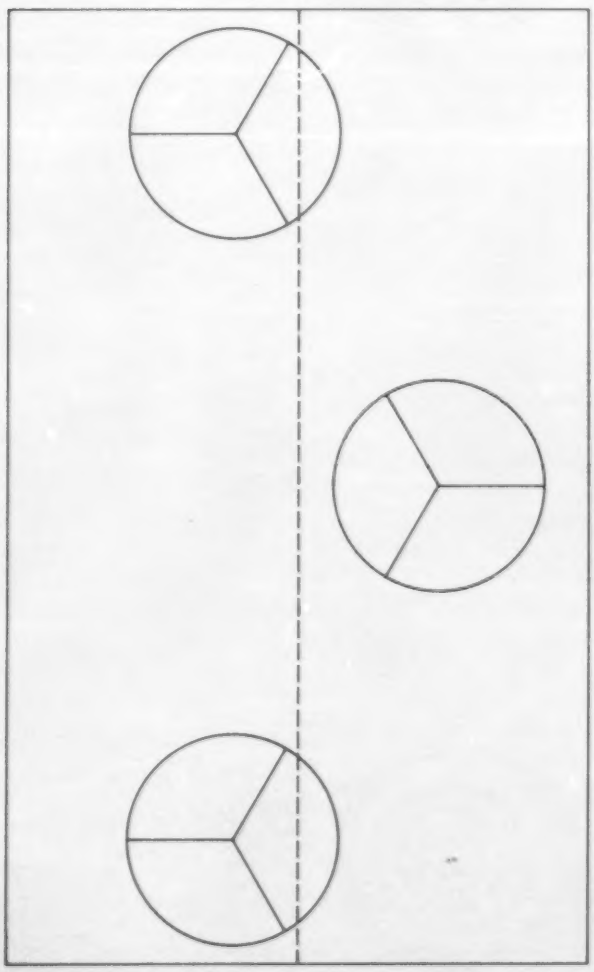

Figure 2. Pattern of hot spots and rift valley systems drawn on Worksheet 1.

3. Use scissors to cut along each straight line of the three-armed rift valley system in each imaginary circular hot spot.
4. Crumple the three pieces of scrap paper into small spherical shapes of about 3 cm in diameter. Next, place Worksheet 1 on your table with a crumpled piece of scrap paper under the center of each imaginary hot spot. Press the Worksheet down onto the crumpled papers.
5. In the space below, write a sentence that describes what hot spots do to the earth's crust (represented by Worksheet 1).

6. Remove the crumpled scrap paper from beneath Worksheet 1. Draw lines to show the connection between the arms of rift valleys that should link up if your imaginary earth's crust continued to split apart. Continue the line as if hot spots existed in alternating positions beyond the top and bottom of Worksheet 1. See Figure 3. Write "active arm" on each of the two arms of each hot spot that connects with rift valley arms of nearby hot spots.

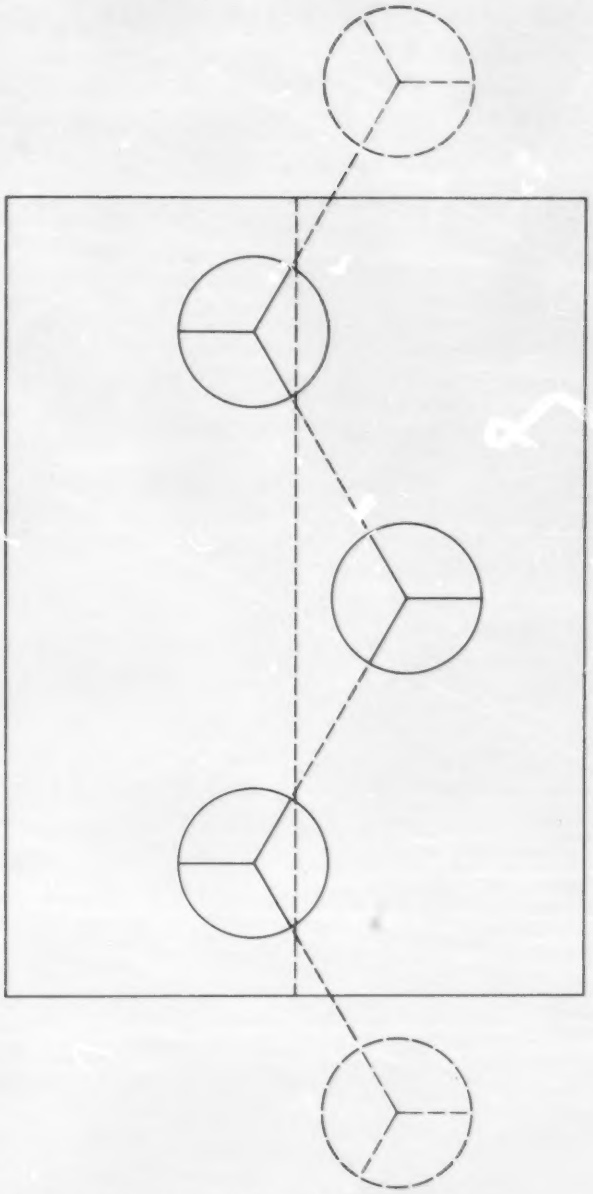

Figure 3. Linkup of rift valleys extending outward from hot spots. Worksheet 1.

7. Cut along the lines that show linkup of rift valleys. (Do not cut along the original dotted line up and down the center of Worksheet 1.) Separate the two halves of Worksheet 1 by about 2 cm. Tape the two halves to a sheet of blank paper. The opening represents an early stage of ocean formation between pieces of a continent that has broken apart.

8. Draw a line midway between the separated pieces of Worksheet 1. Label this line "mid-ocean ridge".

Each hot spot has a rift valley arm that failed to connect with a rift valley arm from another hot spot. Label each of these **"failed arm."** Because each of the failed arms represents a long valley in the earth's crust, a river might begin to flow along the failed arm and into the ocean.

9. Worksheet 2 shows a simplified outline of South America and Africa in a position just after they began to split apart 125 million years ago. Study a map of South America and Africa to find the major rivers that may occupy failed arms of ancient hot spots. Write the names of those rivers in their proper location on Worksheet 2.

10. Draw a hot spot and the three-armed rift valley system on each hot spot where you think it might have been in relation to each river, on Worksheet 2. Remember that these rivers represent the failed arms of the three-armed rift valley system.

SUMMARY QUESTIONS

1. What are hot spots? What are the first changes they cause in the earth's crust?

3. How might linkup of active arms allow formation of an ocean basin?

2. Sketch a diagram to show how three hot spots might link up and label all active arms and failed arms.

4. What might happen to failed arms of hot spots?

EXTENSIONS

Study a map that shows the areas around the Red Sea and Gulf of Aden between northeast Africa and the Arabian Peninsula. Make a sketch map to show how this area might be explained by a hot spot near the junction of the Red Sea and Gulf of Aden.

REFERENCE

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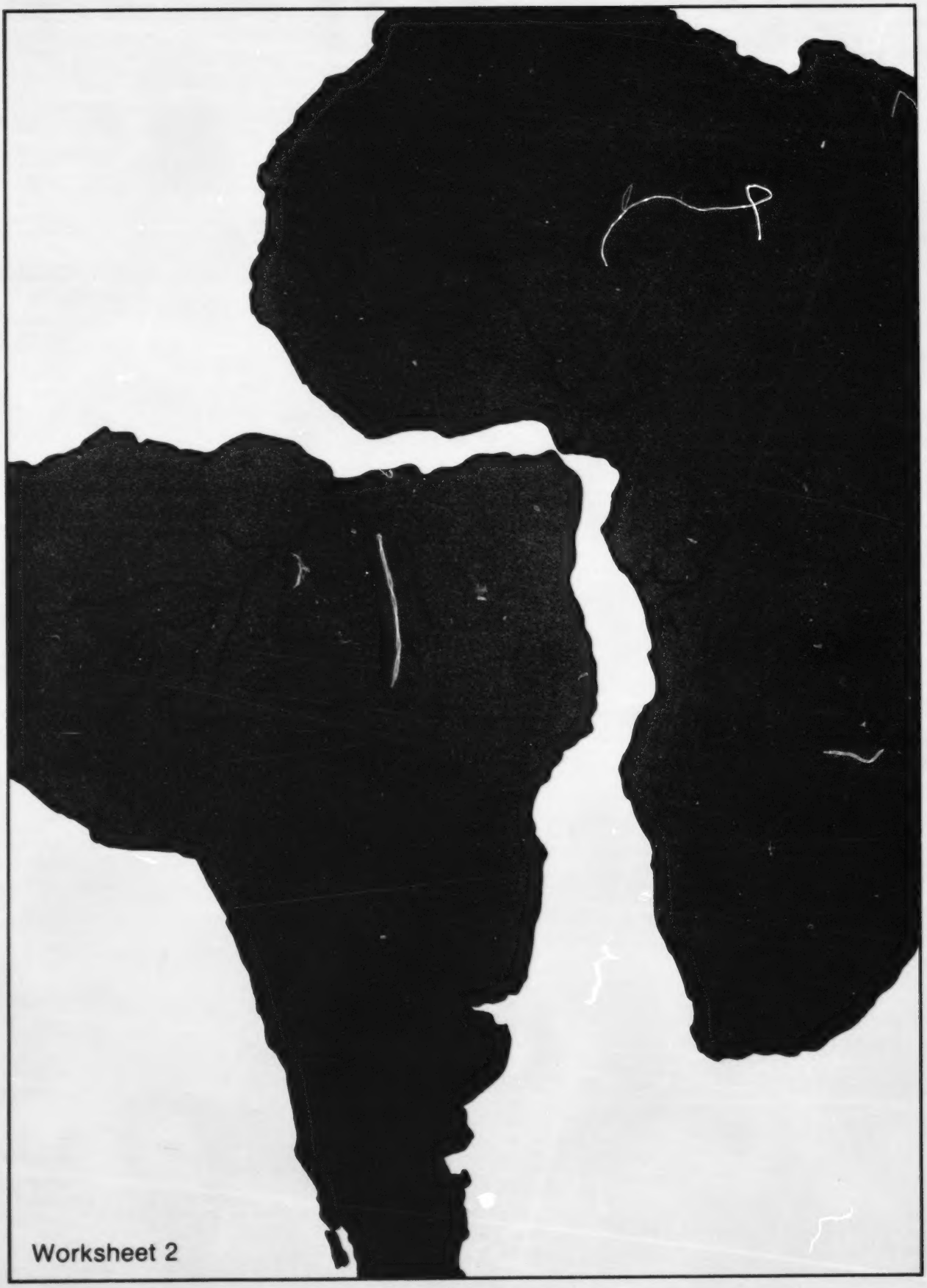

Worksheet 2